NMA Observations of CO(2-1) and CO(1-0) Emission in the Starburst Region of NGC 4527

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Abstract

We have performed high resolution CO(2-1), CO(1-0), HCN(1-0) and HCO^+(1-0) observations of a "low star formation efficiency starburst galaxy" NGC 4527 with the Nobeyama Millimeter Array. The integrated intensity ratios, CO(2-1)/CO(1-0) and HCN(1-0)/CO(1-0), are found to be 0.6±0.05 and 0.06±0.007, respectively, at the center. These line ratios are smaller than those in prototypical starburst galaxies such as NGC 253 and M82, and we suggest that the fraction of dense molecular gas to the total molecular mass in the central a few kpc region of NGC 4527 is small. This fact may be responsible for the low star formation efficiency in the center of NGC 4527.

1 Introduction

NGC 4527 is a nearby spiral galaxy (Table 1), and has been classified as a starburst galaxy because of it's abundant molecular gas ($M_{\mathrm{H}_2} \sim 4 \times 10^9 M_{\odot}$) and high *star formation rate* (Young & Devereux 1991). However, Young & Devereux (1991) pointed out that the star formation rate per unit gas mass indicated by $L_{\mathrm{IR}}/M_{\mathrm{H}_2}$, the *star formation efficiency*, of NGC 4527 is very low compared with their starburst sample. What controls the star formation properties in the central region of NGC 4527? In order to address the relationship between the physical conditions of molecular gas and star formation, we have performed high resolution multiple molecular emission observations in the central a few kpc region of NGC 4527 with the Nobeyama Millimeter Array (NMA).

Parameter	Value	Ref.
Morphology	SAB(s)bc	RC3
	Sb(s)II	RSA
Position of nucleus		(1)
α(B1950)	$12^{\mathrm{h}}31^{\mathrm{m}}35\overset{\mathrm{s}}{.}1$	
δ(B1950)	$+02^\circ 55' 47\overset{''}{.}0$	
Position angle	64°	(2)
Inclination angle	72°	(3)
Adopted Distance	13.5 Mpc	(4)
Linear scale	65 pc arcsec^{-1}	
I_{CO}	15.8 K km s^{-1}	(5)
S_{CO}	658 ± 50 Jy km s^{-1}	(6)

Table 1: Properties of NGC 4527. Reference (1)(2)Hummel et al. 1987; (3) Rubin et al. 1997; (4) Tully 1988; (5)(6) Young & Devereux 1991;

2 Observations

The central region of NGC 4527 was observed in multiple line with the NMA which consists of six 10 m dishes. The observations were made during December 1998 to May 1999. The Ultra Wide-Band Correlator(UWBC) with a bandwidth of 1024 MHz enables us to perform simultaneous observations of both HCN(1-0) and HCO^+(1-0). The uncertainty in the absolute flux scale is estimated to be about ±10%.

3 Results

3.1 CO(1-0)

The CO(1-0) map in Figure 1 shows two outstanding features. One is the strong concentration of CO emission toward the nucleus (r < 5″ or 350 pc) with a slight elongation along the major axis of the galaxy (P.A. = 64°). Another feature is two offset ridges of CO emission extends over r < 27″ (1800 pc) along P.A. of 64°. The overall distribution of the CO in NGC 4527 is very similar to that of barred spiral galaxies, which shows two offset ridges at the leading edges of a bar with a central concentration of gas (e.g., Kenney et al. 1992), although the optical morphology can not make clear whether the presence of the bar (Table 1). Our CO(1-0) map recovers about 80 % of a single dish flux (Young et al. 1995). Molecular gas mass estimated from the observed CO flux is about 1.2×10^9 $M_{\odot}$, and the peak molecular gas surface density, Σ_{H_2}, at the center is 8.8×10^2 $M_{\odot}$ pc^{-2} adopting a Galactic CO-to-H_2 conversion factor (3×10^{20}cm^{-2}(K km s^{-1})$^{-1}$). This velocity width (full width of zero intensity) of 500 km s^{-1} is the same as that of the single-dish line profiles obtained with the FCRAO 14 m (Young et al. 1995) and NRAO 12 m (Helfer & Blitz 1993).

Figure 1: (a)Total intensity distribution of CO(1-0). Contour levels are 1, 2, 4, 6, 8, 10, 15, 20, 25, 30, 35, 40, 45 and 50 σ, where 1 σ = 1.82 Jy beam^{-1} km s^{-1}. A cross (+) marks the field center and radio continuum peak. A∼C indicate the positions where intensity ratios were calculated in Table 3. (b)Total intensity distribution of CO(2-1). Contour levels are 2, 4, 6, 8, 10 and 12 σ, where 1 σ = 12 Jy beam^{-1} km s^{-1}. (c)(d)Total intensity distribution of HCN(1-0) and HCO^+(1-0), respectively. Contour levels are 1, 2, 3, 4, 5, 6, 7, 8 and 9 σ, where 1 σ = 0.756 Jy beam^{-1} km s^{-1}.

3.2 CO(2-1)

The distribution of the CO(2-1) emission resembles the CO(1-0) map, although the extended ridges seen in CO(1-0) map (r < 27″ or 1800 pc) do not appear in this CO(2-1) map. It is probably due to insufficient sensitivity of CO(2-1) observations, and also the lack of short spacing. The summary of CO observations are listed in Table 2.

3.3 HCN(1-0) and HCO^+(1-0)

HCN(1-0) and HCO^+(1-0) emission concentrated toward the center have been detected. Extended components correspond

Line and transition	CO(2-1)	CO(1-0)	CO(1-0) (UV tapered 40 kλ)	HCN(1-0)	HCO^+(1-0)
Array	D	AB, C, D	AB, C, D	C, D	C, D
Synthesized beam	$4''.7 \times 3''.6$ (300 × 230 pc)	$4''.0 \times 2''.0$ (260 × 130 pc)	$6''.0 \times 3''.5$ (390 × 230 pc)	$7''.0 \times 6''.0$ (460 × 390 pc)	
Peak integrated intensity	330 K km s^{-1}	600 K km s^{-1}	420 K km s^{-1}	26 K km s^{-1}	23 K km s^{-1}
Total integrated flux	1020 Jy km s^{-1}	540 Jy km s^{-1}	560 Jy km s^{-1}	17 Jy km s^{-1}	17 Jy km s^{-1}

Table 2: NMA observations.

Galaxy	Star formation or Position	$R_{2-1/1-0}$	Ref.	$R_{\mathrm{HCN/CO}}$	Ref.	$R_{\mathrm{HCO^+/HCN}}$	Ref.
NGC 4527	A (r = 400 pc)	0.48	(1)	0.052	(1)	1.0	(1)
	B (r < 200 pc)	0.58	(1)	0.060	(1)	0.9	(1)
	C (r = 400 pc)	0.48	(1)	0.060	(1)	1.0	(1)
NGC 253	nuclear starburst	1.1	(2)	0.3	(6)	0.9	(10)
M82	nuclear starburst	1.3	(3)	0.2	(7)	2.0	(10)
IC 342	moderate starburst	1.1	(4)	0.16	(8)	0.5	(10)
Milky Way	recent burst of star formation	0.65	(5)	0.08	(9)	···	···

Table 3: Integrated intensity ratios of NGC 4527 and other galaxies. A∼C indicate the positions where intensity ratios were calculated in Figure 1a. Reference. (1)this work; (2)Aalto et al. 1995; (3)Wild et al. 1992; (4)Eckart et al 1990; (5)Oka et al. 1996; (6)Sorai 1997; (7)Shen & Lo 1995; (8)Downes et al. 1992; (9)Jackson et al. 1996; (10)Rieu et al. 1992;

to the CO ridges may be also seen in the maps, although the S/N ratios are insufficient to make detail comparisons. We assumed almost all the single dish flux is recovered in both HCN and HCO^+ maps, and the previous observations of HCN emission seems to support the validity of this assumption (see Helfer & Blitz 1997 and Kohno et al. 1999a). We summarize HCN and HCO^+ observations in Table 2.

4 Discussion

4.1 Integrated intensity ratios

The CO(2-1) to CO(1-0) integrated intensity ratio, $R_{2-1/1-0}$, is a measure of dense gas fraction to the total molecular gas (e.g., Sakamoto et al. 1994), and sensitive in a density range of about 10^2 - 10^4 cm^{-3}. We convolved the CO(1-0) map to the same beam size as that of the CO(2-1) to calculate $R_{2-1/1-0}$ values. The peak $R_{2-1/1-0}$ of about 0.6 at the center of NGC 4527 is somewhat smaller than $R_{2-1/1-0}$ values($\sim$ 0.89) in the central regions of spiral galaxies (Braine & Combes 1992), suggesting a presence of a large amount of low density molecular gas in this region. Note the observed $R_{2-1/1-0}$ could contain considerable error due to lack of single dish CO(2-1) measurements, however. A radial decrease of $R_{2-1/1-0}$ may be apparent; the ratio is about 0.6 at the center, while the ratio decreases to 0.5 at r = $6''$ (400 pc).

The HCN(1-0) to CO(1-0) integrated intensity ratio, $R_{\mathrm{HCN/CO}}$, is another measure of dense gas fraction to the total molecular gas (e.g., Kohno et al. 1999), and sensitive in a density range of about 10^3 - 10^5 cm^{-3}. The observed peak $R_{\mathrm{HCN/CO}}$ of 0.06 is significantly smaller than a $R_{\mathrm{HCN/CO}}$ values in starburst galaxies such as NGC 253 (0.2 $\sim$ 0.3; e.g., Paglione et al. 1997; Sorai 1997) and M82 ($\sim$ 0.2; Shen & Lo 1995), and is similar to those in "normal" galaxies such as the Galactic Center ($R_{\mathrm{HCN/CO}} \sim 0.08$; Paglione et al. 1998).

4.2 Dense molecular gas and star formation

Because stars are formed from dense cores of molecular clouds rather than their diffuse envelopes(e.g. Lada 1992), study of dense molecular gas is essential to understand star formation in galaxies. In fact, good spatial coincidence between HCN and Hα emission has been reported in nearby starburst galaxies (e.g. Paglione et al. 1997; Kohno et al 1999).

Both $R_{2-1/1-0}$ and $R_{\mathrm{HCN/CO}}$ suggest that the fraction of dense molecular clouds to the total molecular gas in the center of NGC 4527 is smaller than that of prototypical starburst galaxies such as NGC 253 and M82.

It has been demonstrated that the fraction of dense molecular gas measured with the $R_{\mathrm{HCN/CO}}$ correlates with the star formation efficiency (Solomon et al. 1992), which is indicated by $L_{\mathrm{IR}}/L_{\mathrm{CO}}$.

Considering these results, we suggest that the small dense gas fraction is responsible for the low star formation efficiency in the center of NGC 4527. But the star formation rate of NGC 4527 would be enhanced existence of rich gas in central region.

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